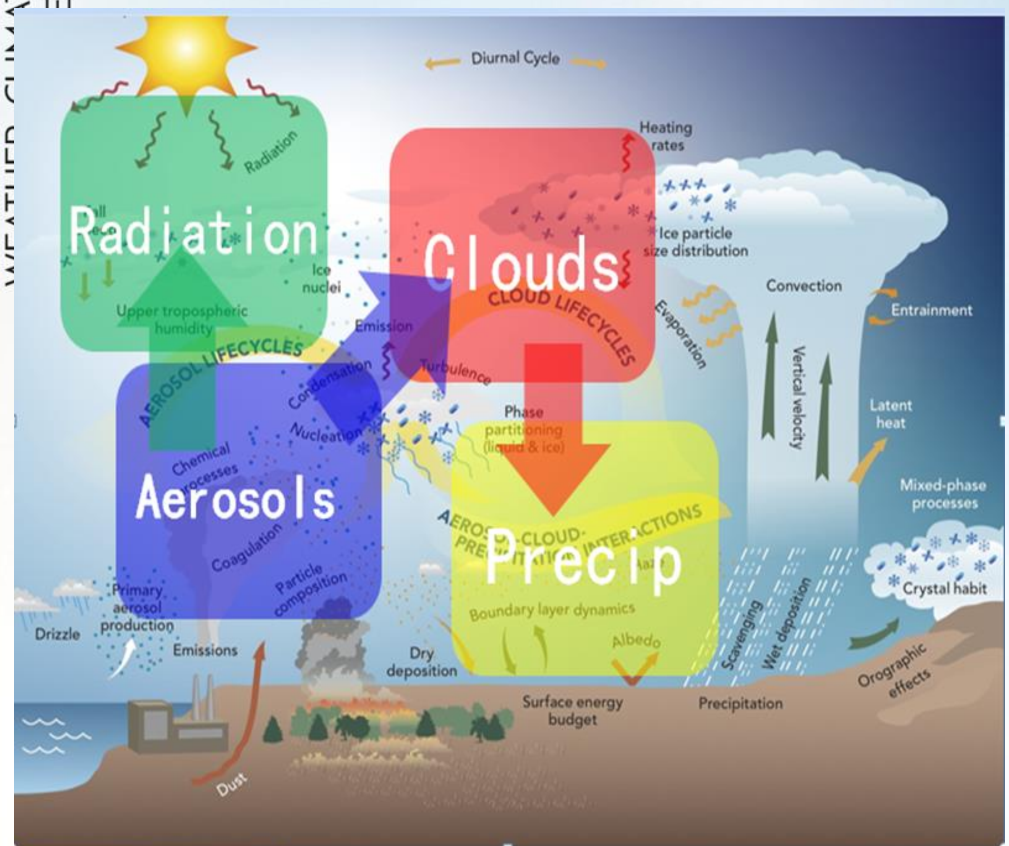
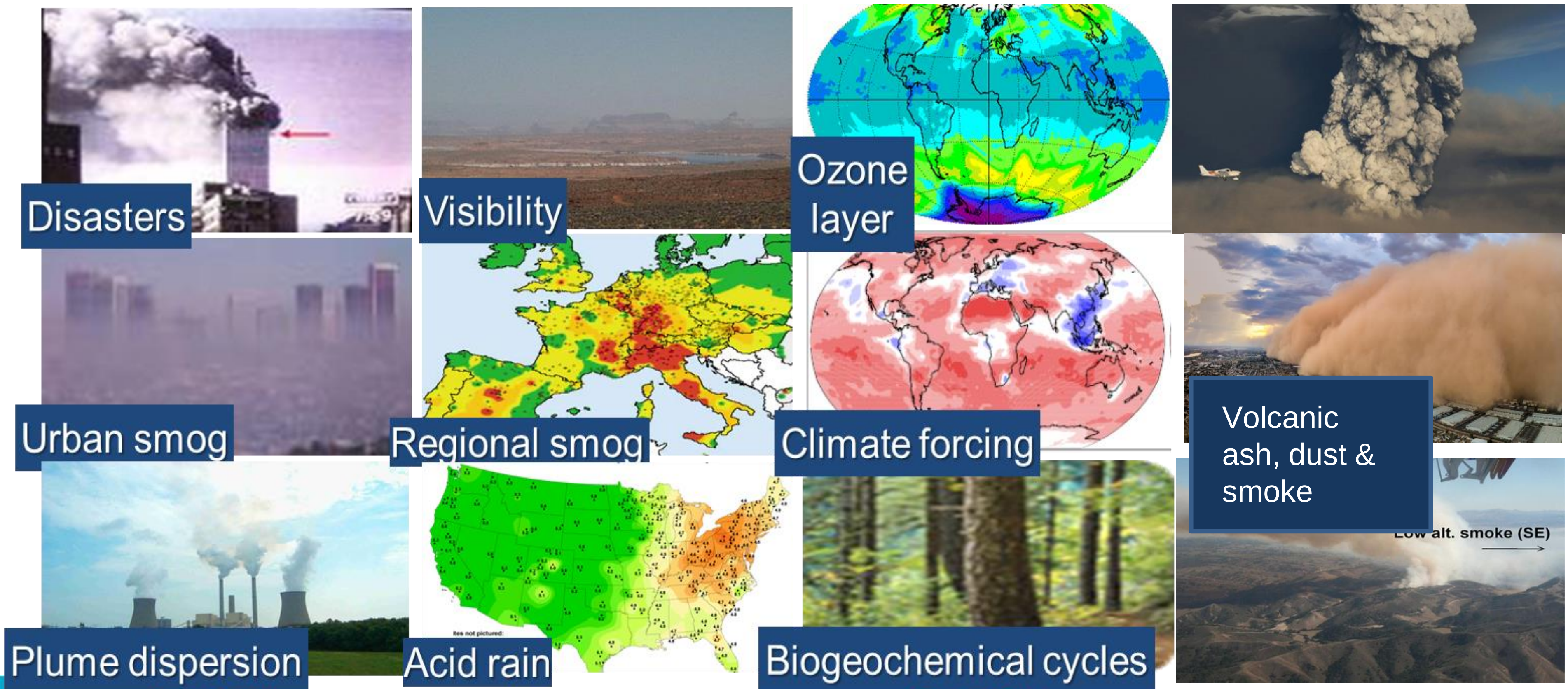
Improving Air Quality (and weather) Predictions via Closer Integration of Observations and Models

Greg Carmichael, University of Iowa, Chair SSC WMO Global Atmospheric Watch Program)



- ✓Trend toward closer linkages of weather, atmospheric composition, and climate related services
- ✓Information needed at higher resolution (and longer lead times) to address societal needs
- ✓Further improvements require advances in observing systems, models and assimilation systems

Atmospheric Composition Matters: To Air Quality, Weather, Climate and More



LOCAL
< 100 km

REGIONAL
100-1000 km

GLOBAL
> 1000 km

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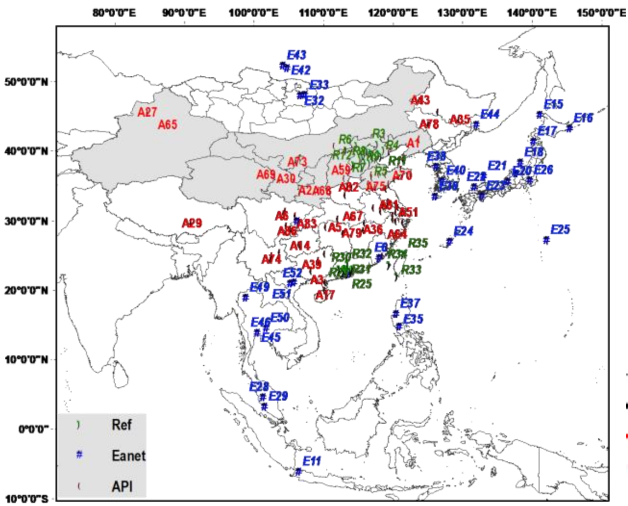
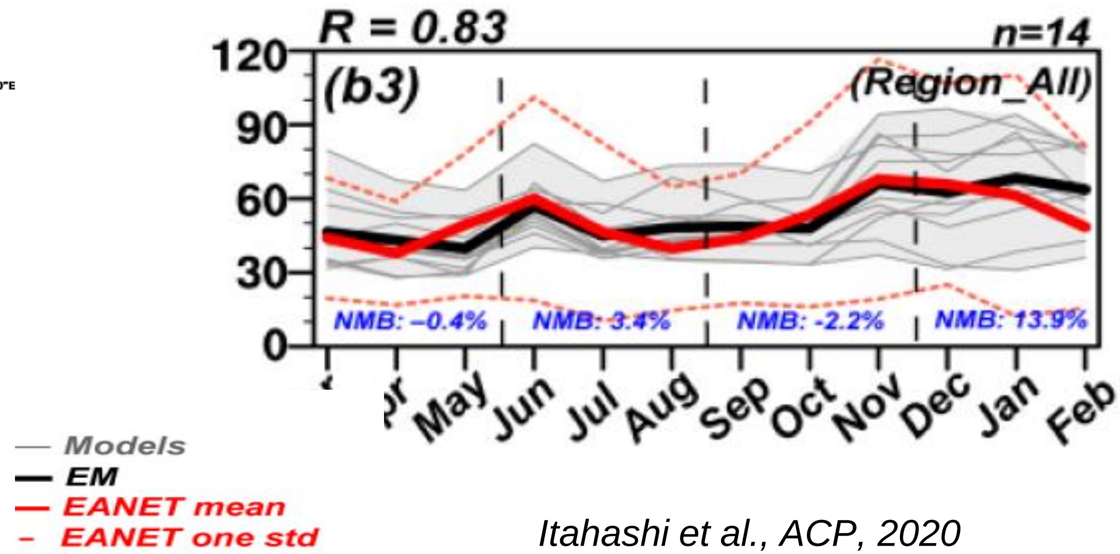
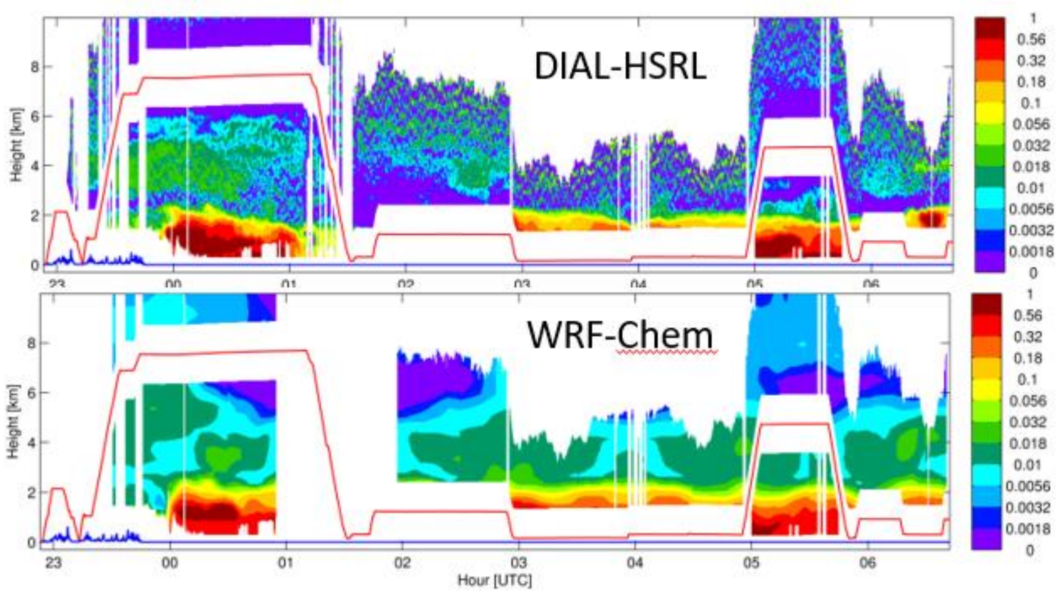
The University of Iowa

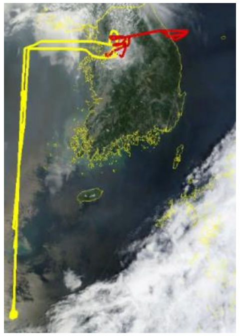
Current Air Quality Models have appreciable prediction skill





Itahashi et al., ACP, 2020

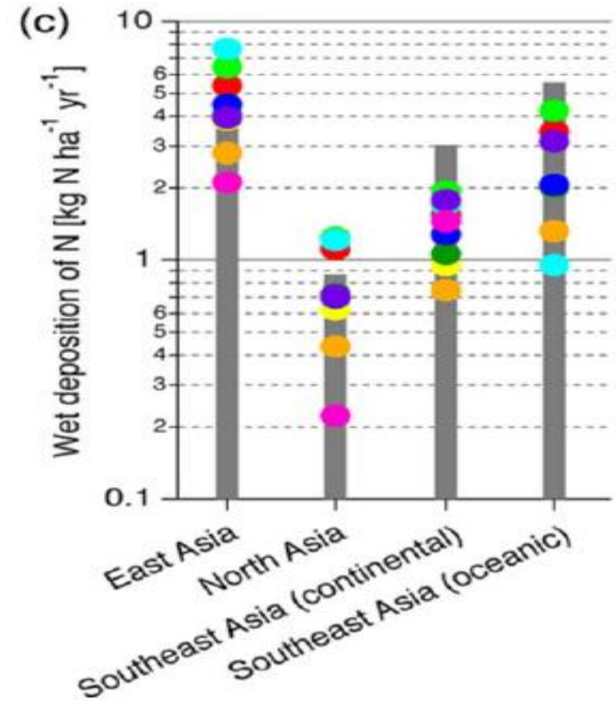




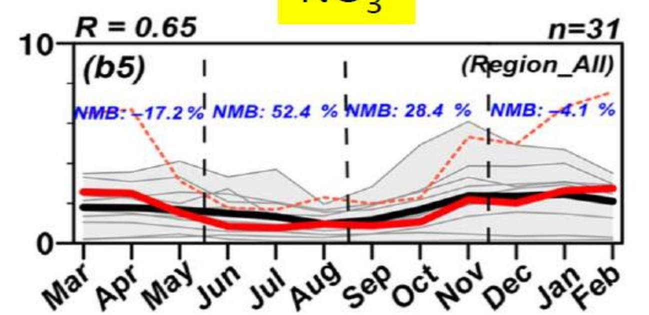
Major sources of uncertainty in AQ Model

- Emissions (anthropogenic and natural (e.g., biomass burning, wind blown dust)
- Meteorology
  - Clouds (photolysis rates, aqueous chemistry, redistribution)
  - Precipitation (removal by scavenging)
  - Planetary boundary layer height
- Process understanding (chemistry, dry deposition, etc.)

Wet Dep of N



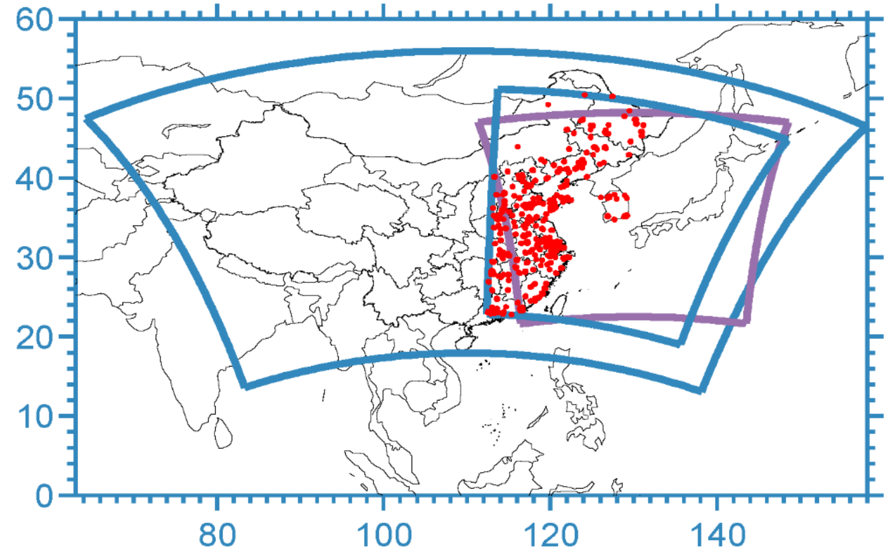
NO_3^-

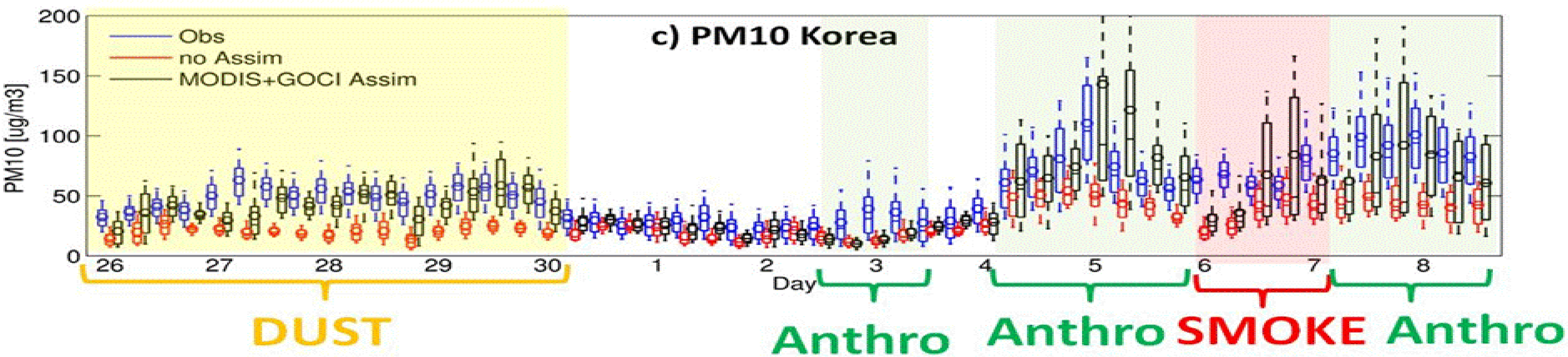


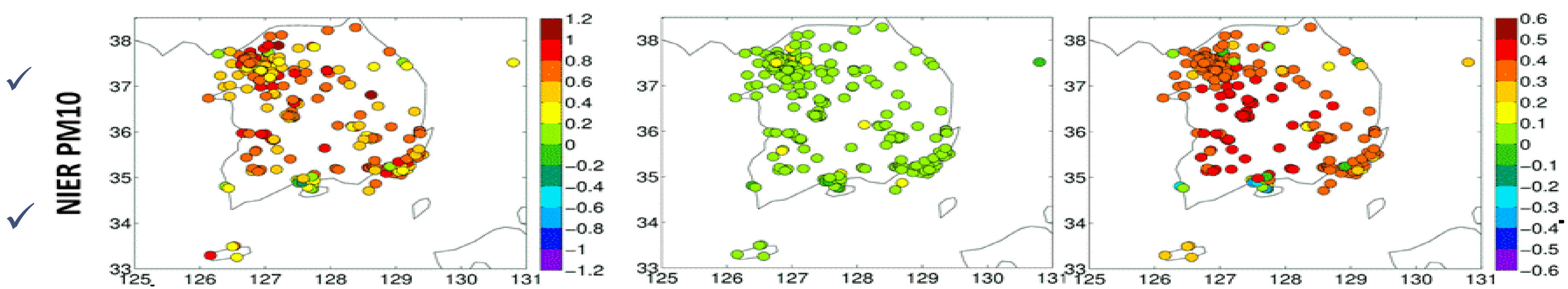
Itahashi et al., ACP, 2020

PM is most important in AQ – AOD assimilation is the current focus.

Testing the Impact of GOCI AOD Assimilation ***UIOWA/UCLA WRF-Chem forecasting system***



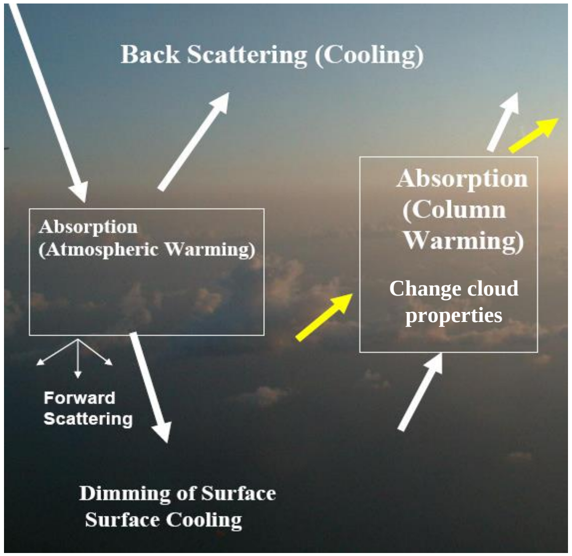




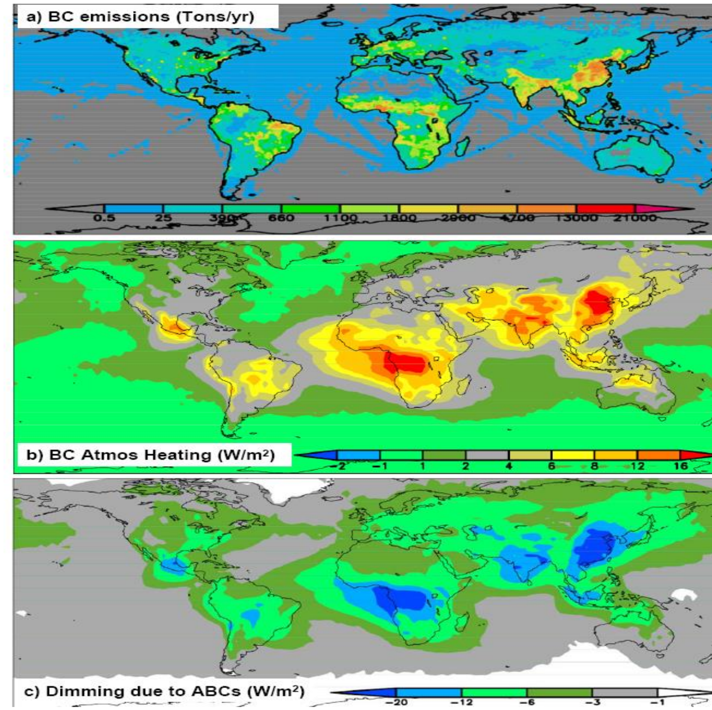
Saide et al., GRL, 2014

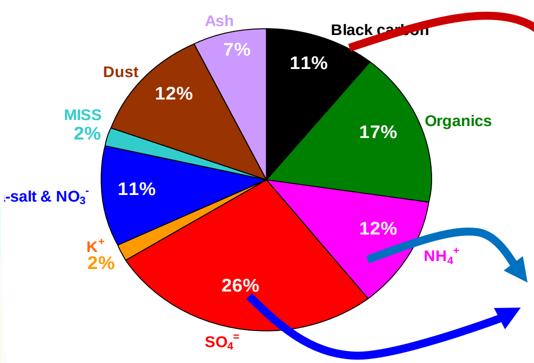
Fractional Bias reduction

Air Pollutants also Impact Weather & Climate -- *Aerosol composition matters*



- ➢Aerosols mask about 50% of the forcing of GHGs.
- ➢BC acts like CO2 with about 50% of forcing as CO2, but with a much shorter atmospheric lifetime.
- ➢Aerosols impact atmospheric stability, PBL height – absorption plays a critical role





Traps sunlight and heats the air

Reflects sunlight like mirrors and cool

Leading to less photosynthetic energy at the surface, changes in clouds, winds and surface temperatures

V. Ramanathan, and G. Carmichael, Nature Geos. 2008

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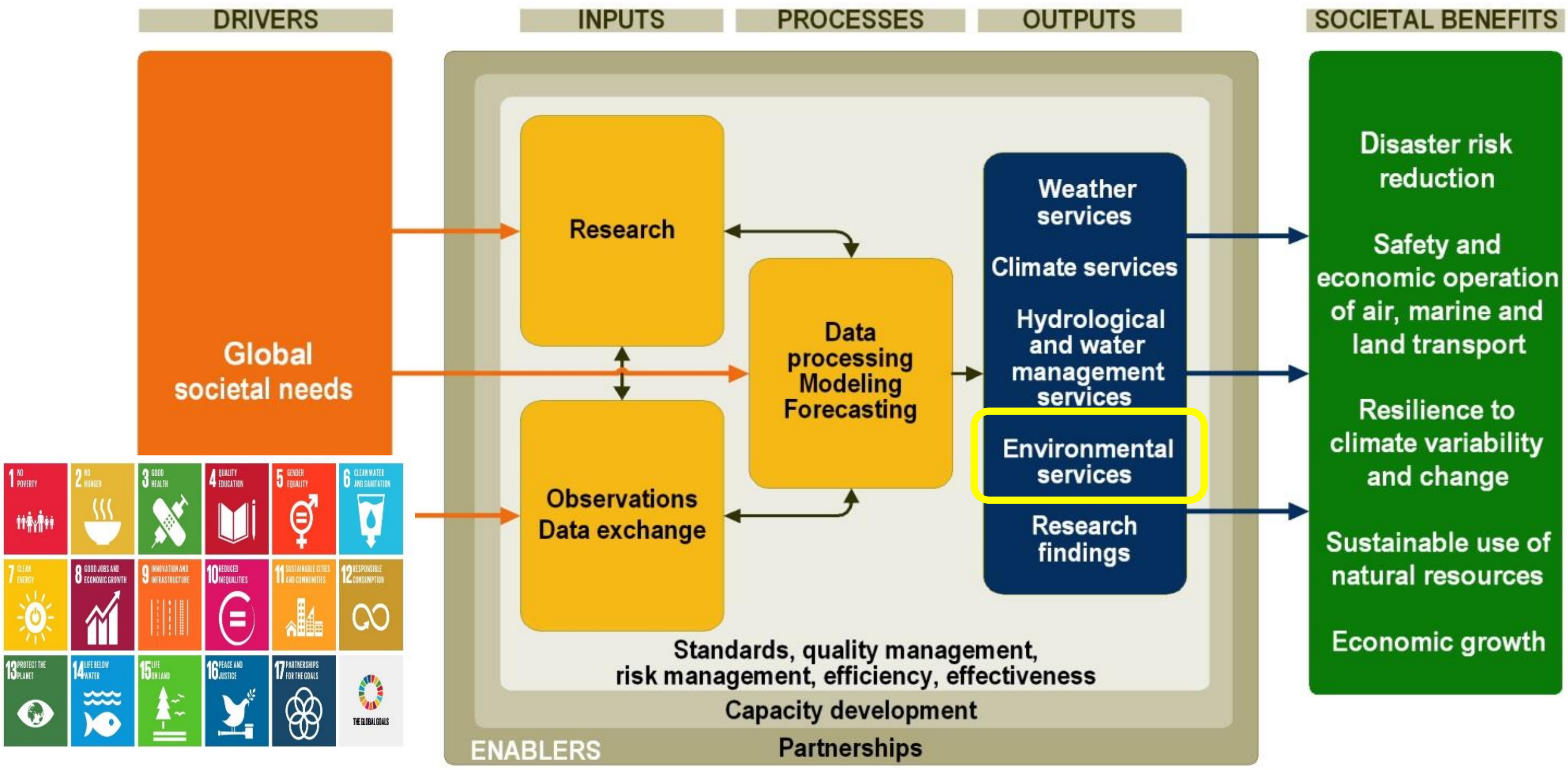
Overarching Objective - Improve Prediction Capabilities via Incorporating/Integrating Composition, Weather and Climate

Earth Systems Modeling Approach



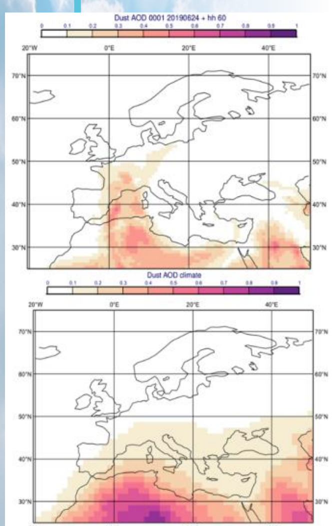
WMO OMM

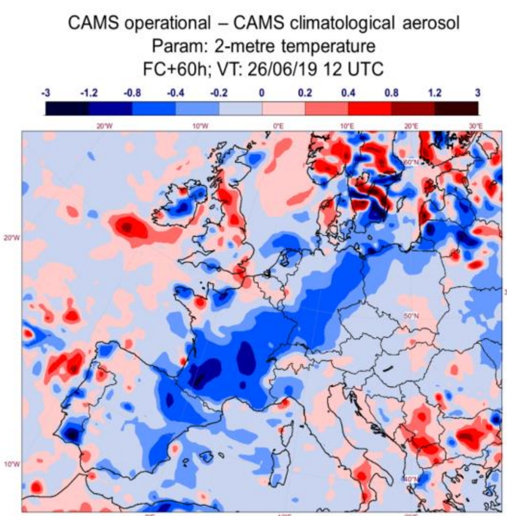
Seamless Prediction *Across all Relevant Temporal and Spatial Scales (**GDPFS**)*

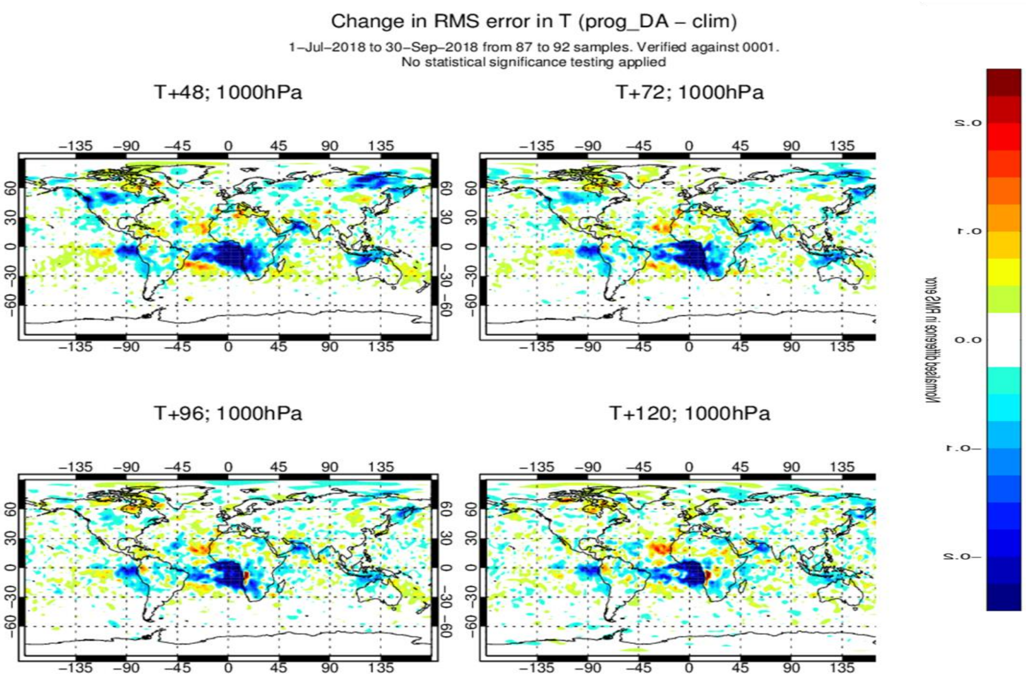
Composition and Weather Forecasting (CAMS at ECMWF)

Up to 1 K cooling of 2m Temperature because of Dust Transport in Europe (June 2019)

Difference in RMSE of temperature at 1000 hPa against analysis between prognostic and climatological aerosol and ozone. Blue areas indicate an improvement with prognostic aerosols and ozone.





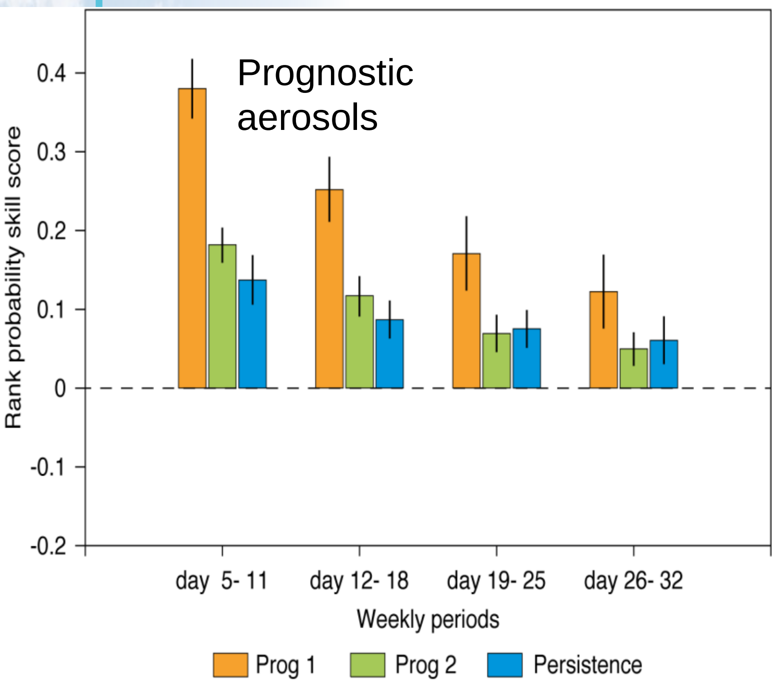


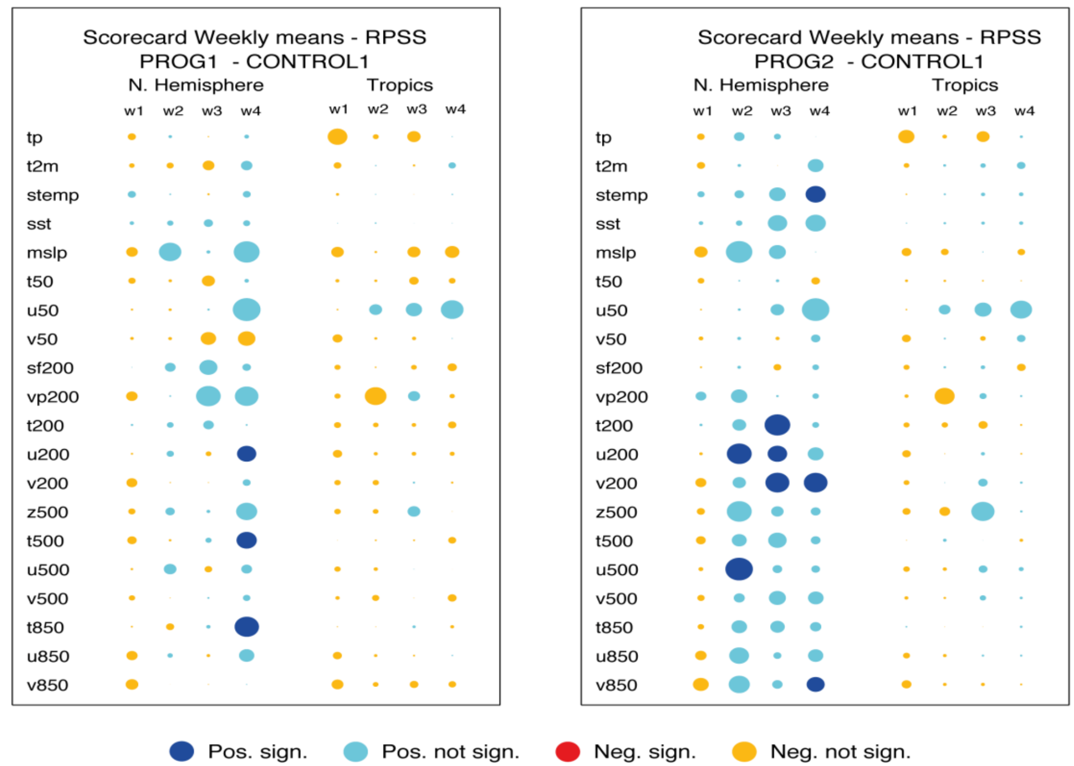
V-H Peuch, ECMWF private comm, 2020

Atmosphere Monitoring

Aerosol impacts at the S2S scales

Results summarized in **Benedetti and Vitart, MWR, 2018**





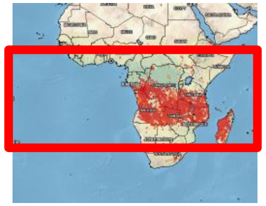
Aerosol impacts on the monthly forecasts: Rank probability skill scores

Models Constrained With Observations Play Increasing Important Roles In Research and Applications

Little experience with coupled models!

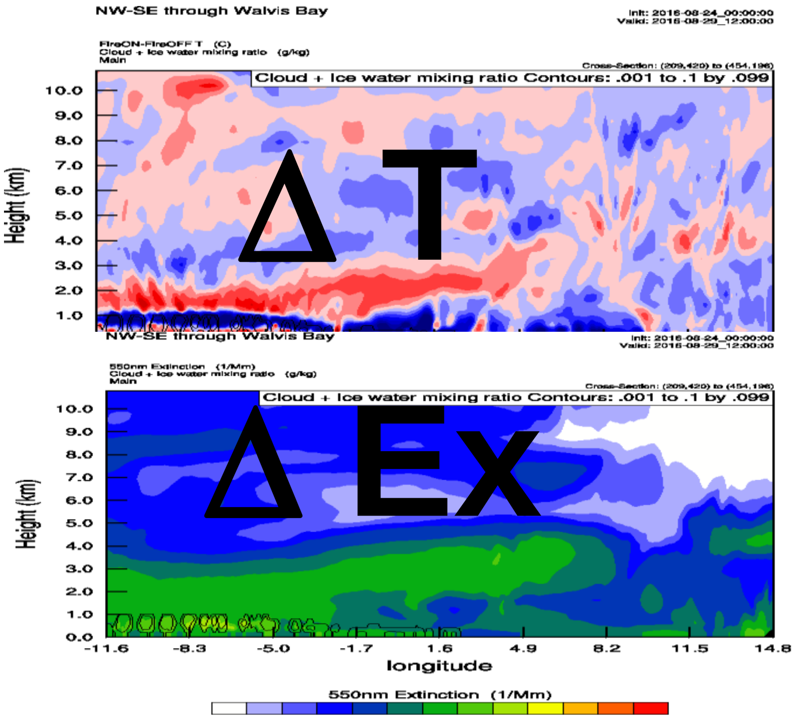
- ✓Need for ***More*** aerosol and atmospheric composition data for use in assimilation
- ✓New observations streams are in the pipe-line …
- ✓Need to improve our forward models

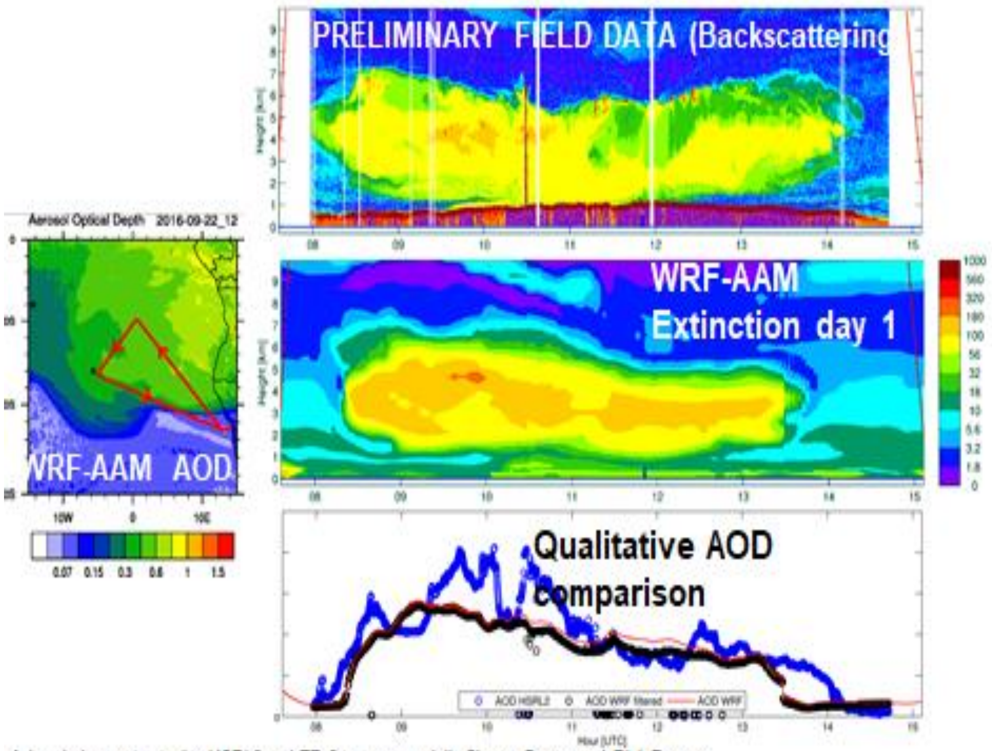
Putting the pieces together Emission inversion and feedbacks (UCLA/IOWA)



- ✓ WRF with aerosol-aware microphysics (AAM): **96 hrs**
  - Based on Thompson and Eidhammer (JAS, 2014) and Saide et al. (JGR, 2016), 12km resolution
  - Smoke emissions constrained in near-real time using Saide et al. (GRL 2015) over 6 regions for 8 hour intervals
  - Simulations turning on and off fires to assess aerosol-cloud-radiation interactions
  - Source identification
  - Full chemistry (gases and aerosol composition)

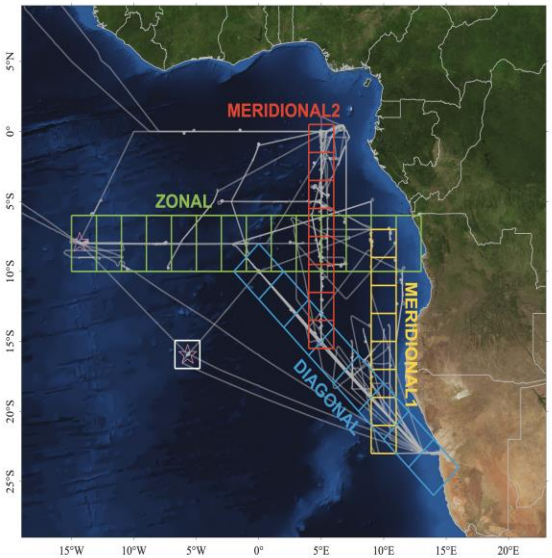
HSRL2 data from ER-2 aircraft (Sept 22nd)





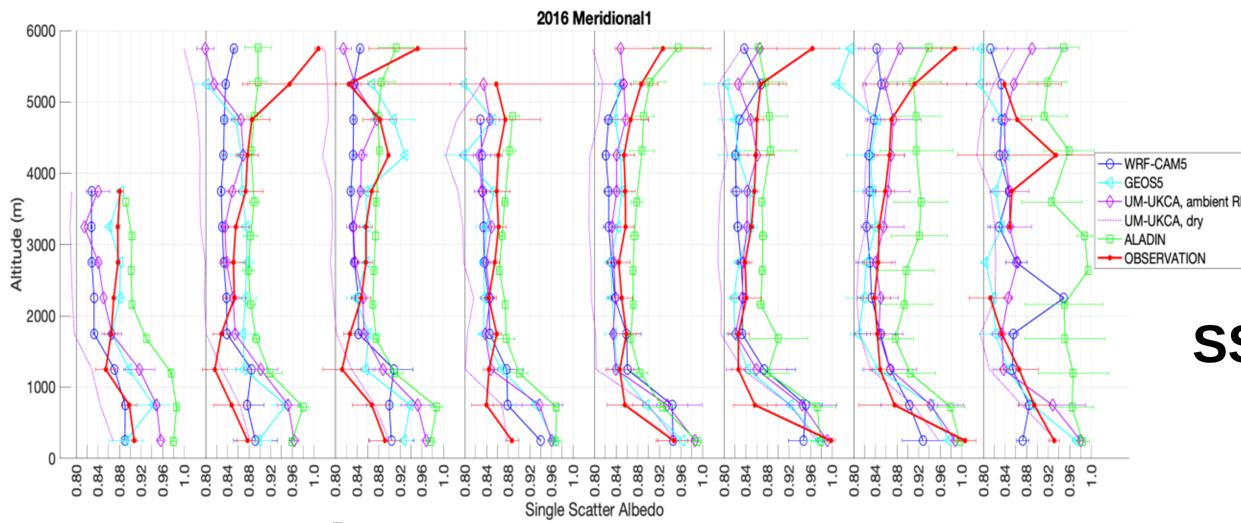
Acknowledgements to the HSRL2 and ER-2 teams, specially Sharon Burton and Rich Ferrare

Vertical information is needed to test/improve predicted aerosol properties important to weather and climate



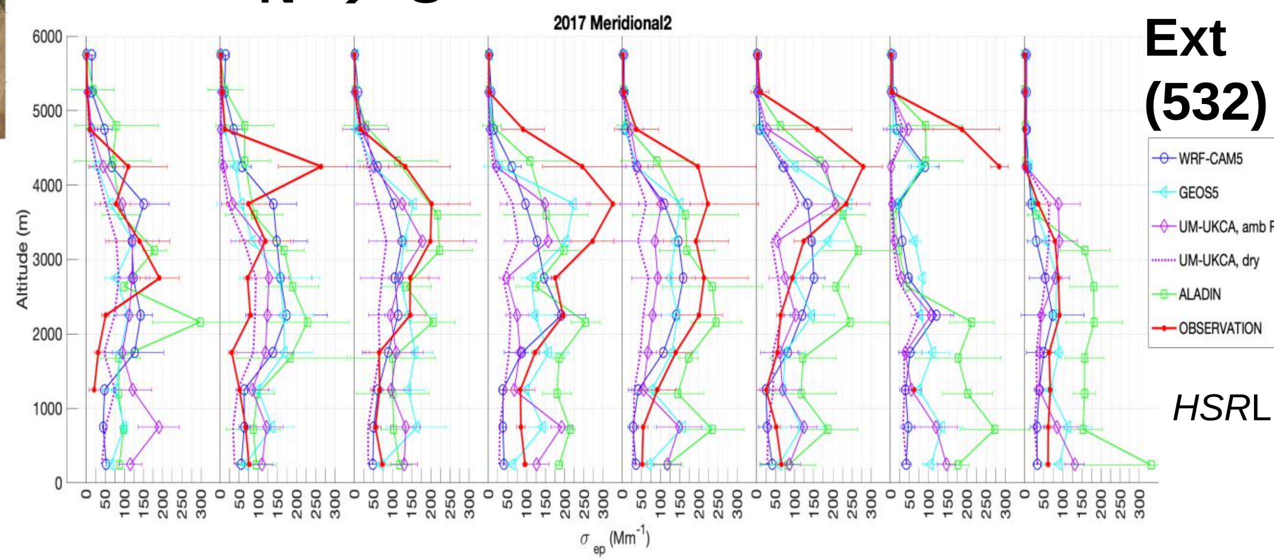
Doherty et al., in prep.

Shinozuka et al., ACP, 2022



SSA

N → S

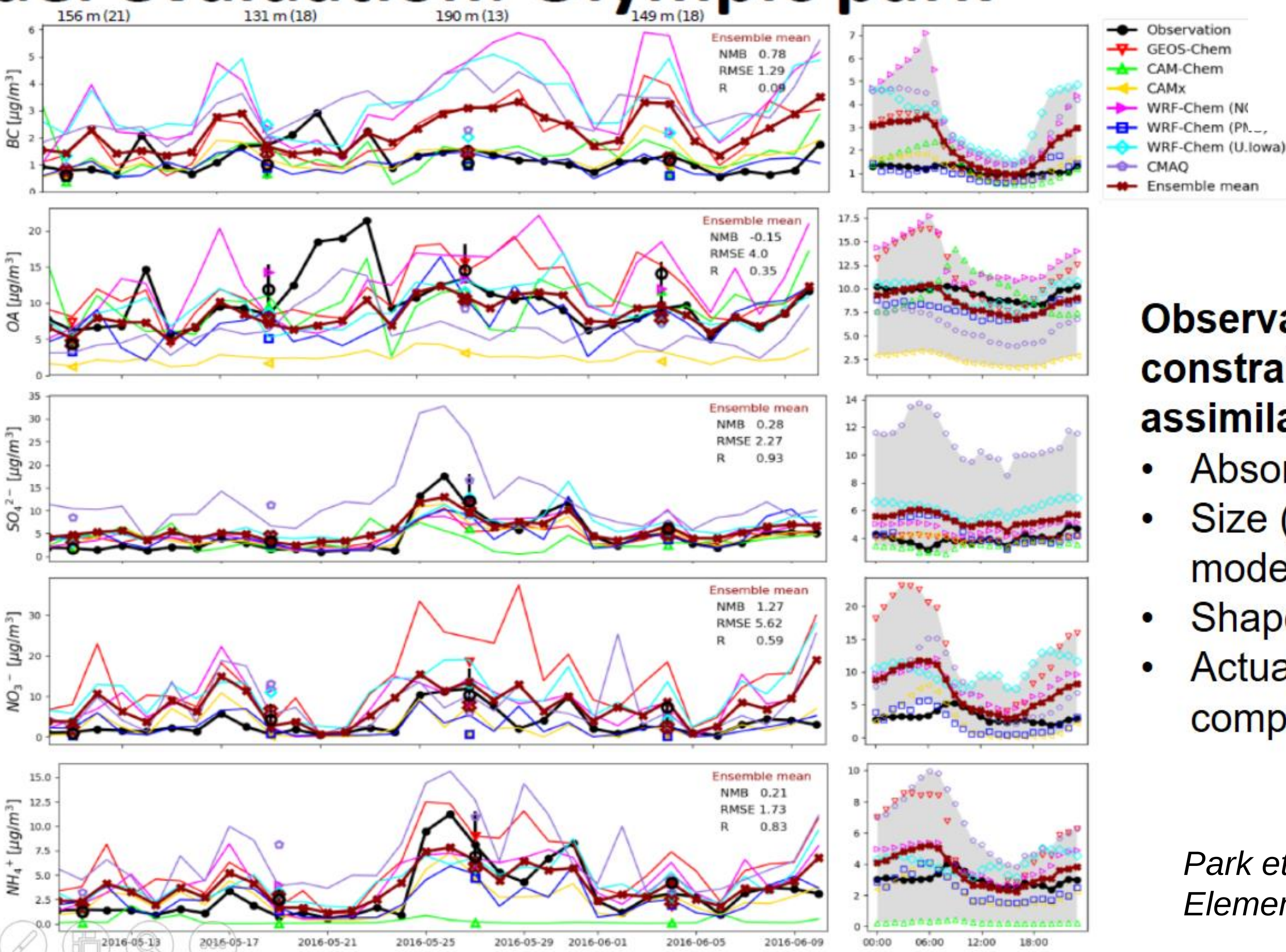


Ext (532)

HSRL

There is also the issue of improving predictions of aerosol composition

Model evaluation: Olympic park

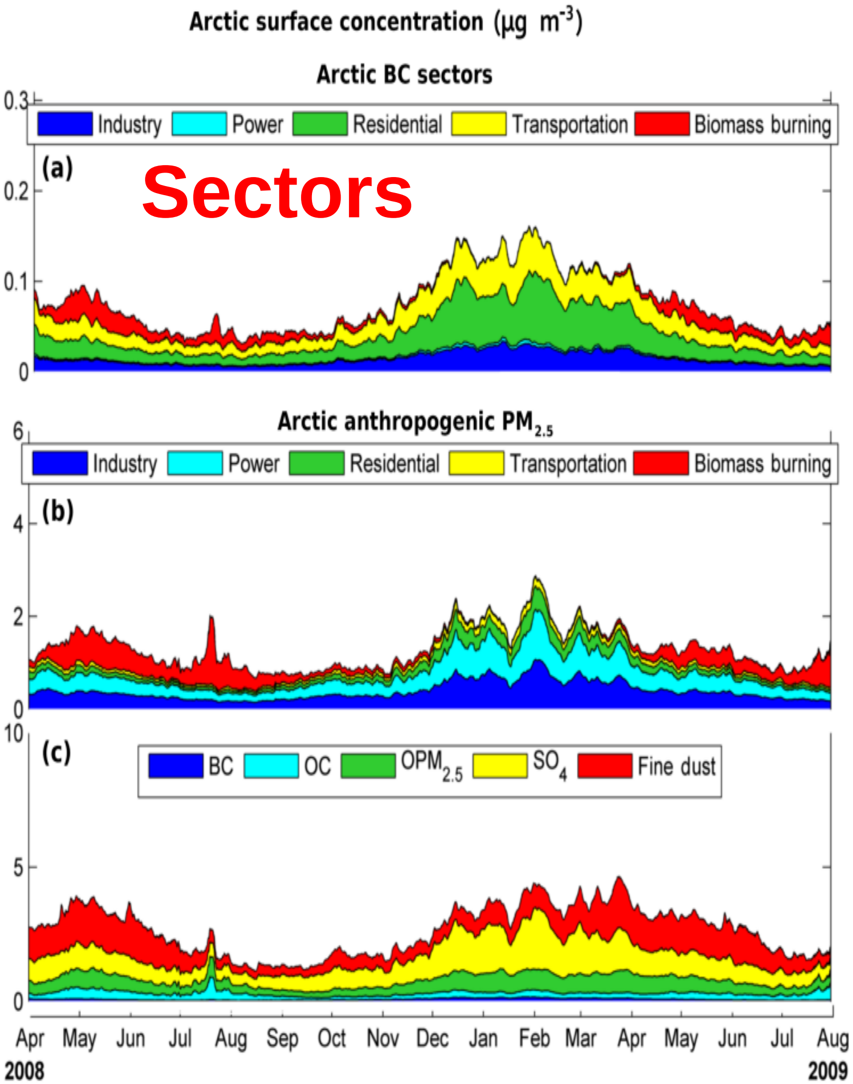


Observational constraints for assimilation:

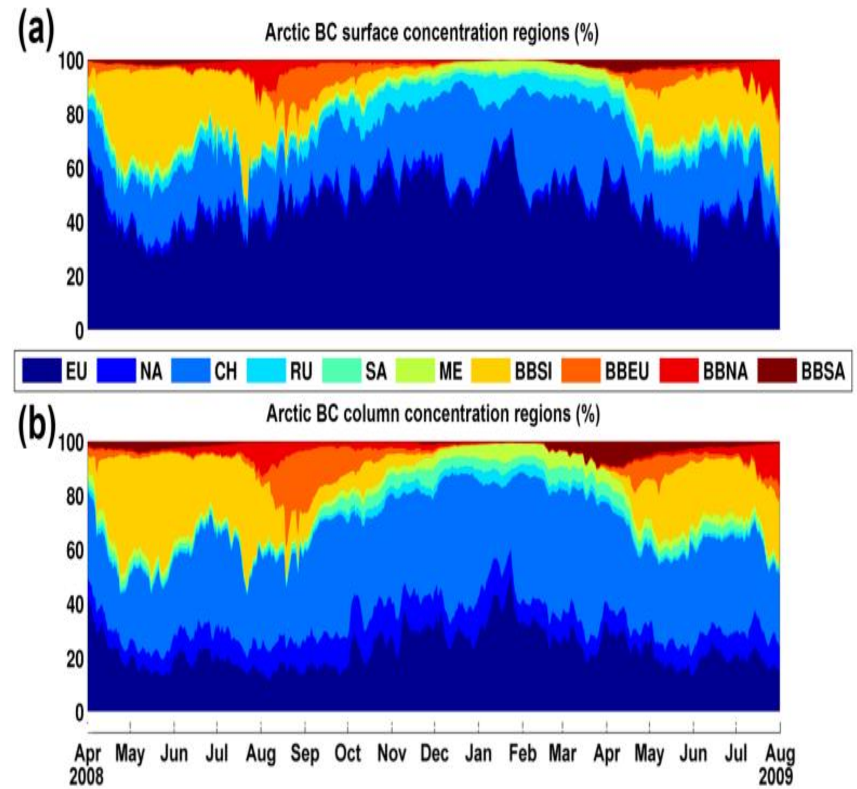
- Absorption
- Size (fine model)
- Shape
- Actual composition

Park et al., Elementa, 2021

Source Attribution (sector/region/anthropogenic) is Becoming an Important Component of Air Quality Predictions

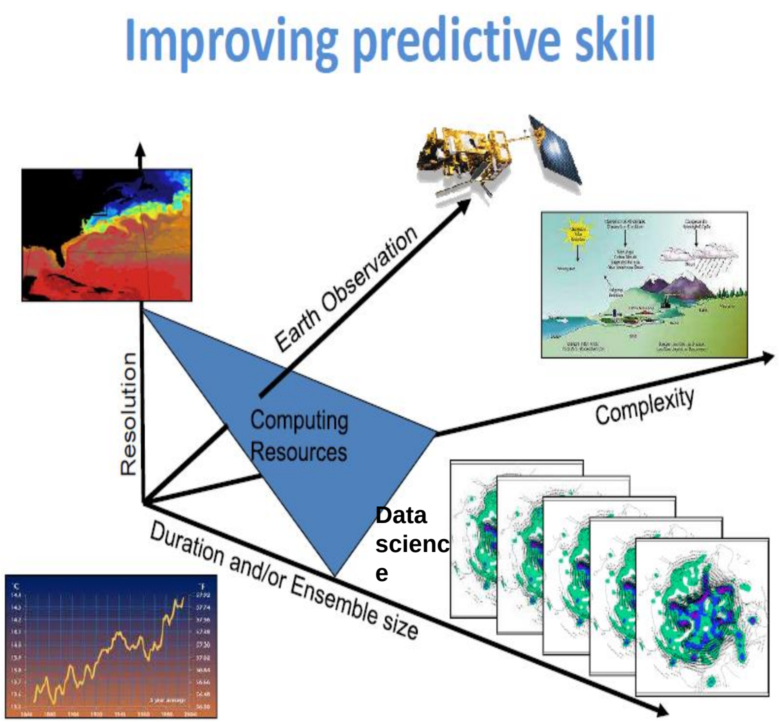


Regions



Sobhani et al., ACP, 2018

Improving Air Quality Predictive Capabilities
Exciting Times Ahead!!

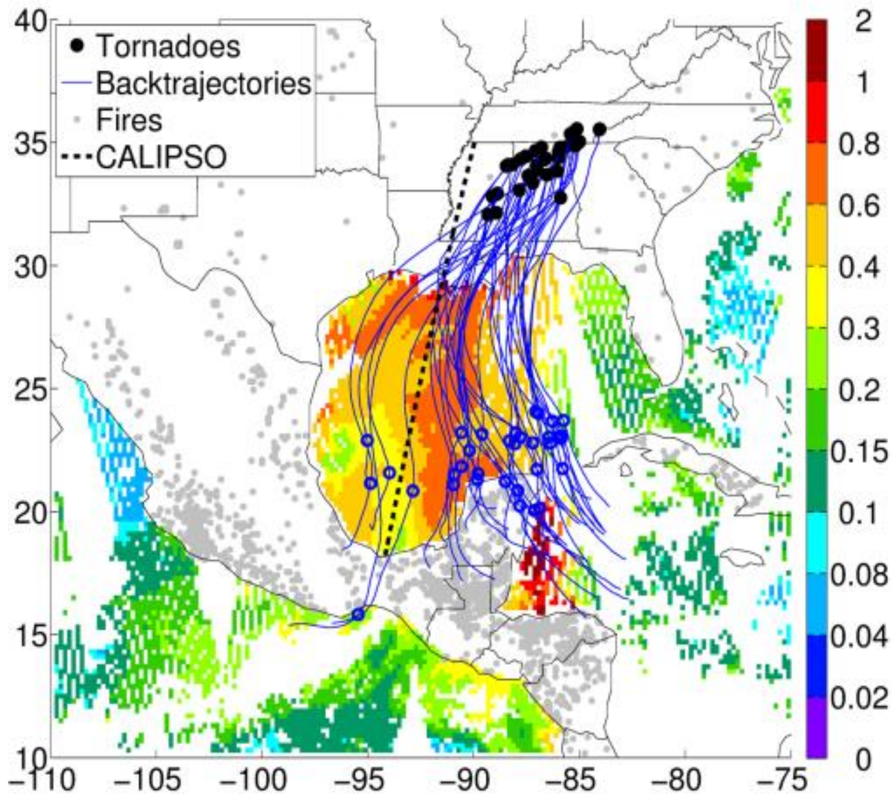


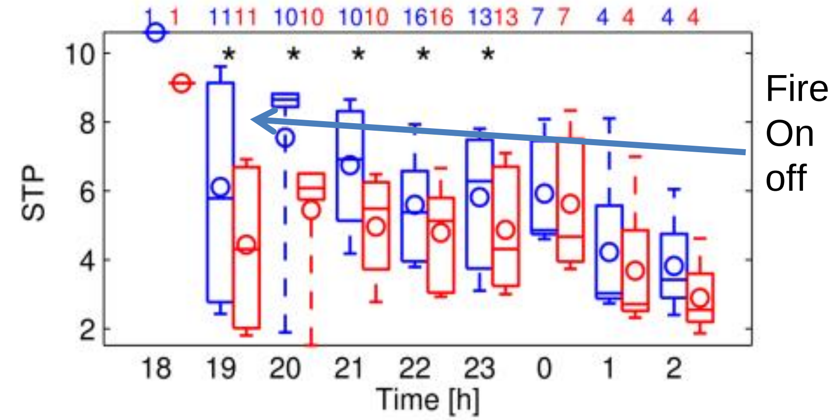
- ✓Trend toward closer linkages of weather, atmospheric composition, and climate related services
- ✓Information needed at higher resolution (and longer lead times) to address societal needs
- ✓Further improvements require advances in observing systems, models and assimilation systems
- ✓ Need to continue to develop Earth System approach
- ✓Atmospheric composition observing system is expanding in important ways (e.g., GEMS, TEMPO)
- ✓ACCP offers a great opportunity to advance our capabilities to understand and model aerosol processes and their interactions with weather and climate

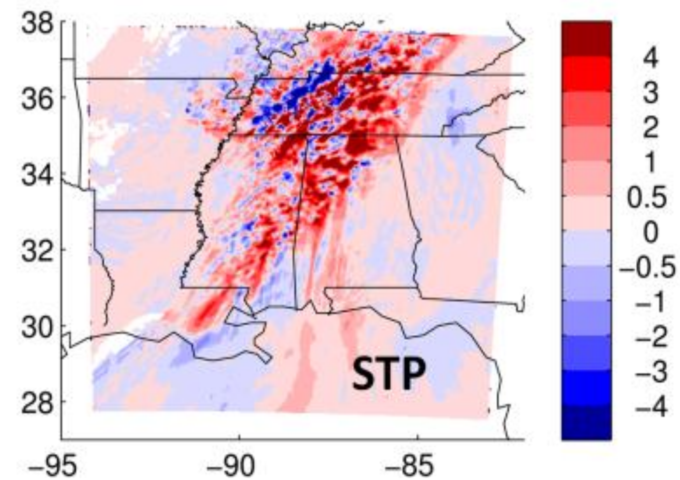
Backup slides

Application #5. Severe Storm (tornado) Prediction

Saide et al., 2014 in review



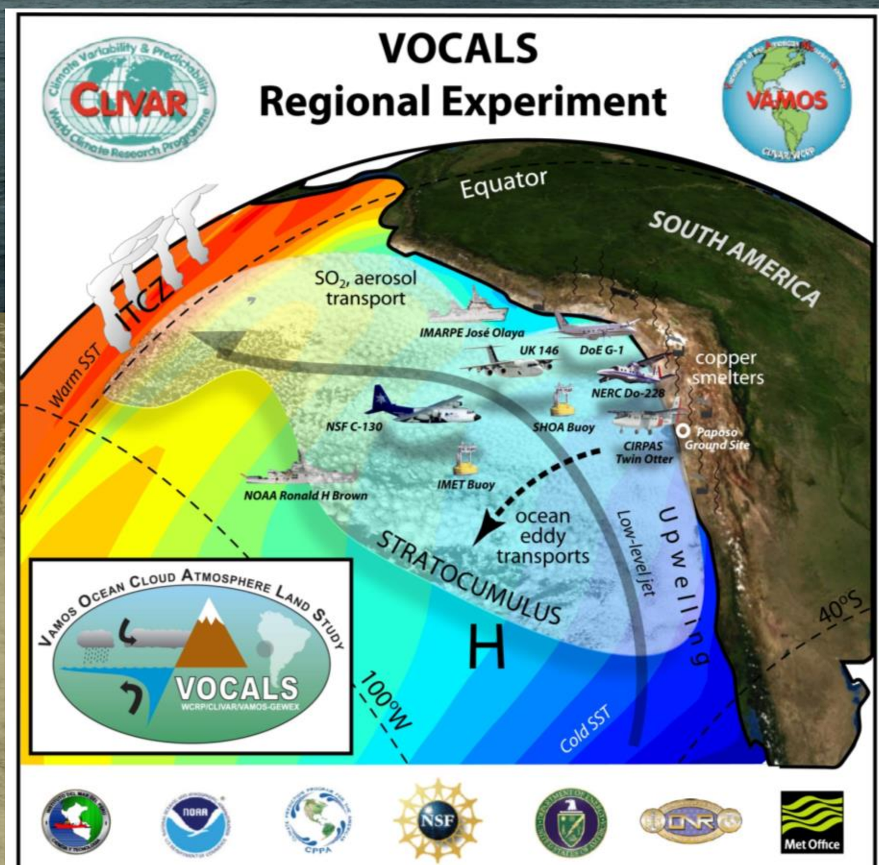




*Biomass burning smoke before and during the severe weather outbreak of April 27 and modeled impacts on tornado parameters. Left: 42 hour back trajectories from the beginning of violent tornado tracks, with circles marking 24 hour, observed AOD over ocean on 27 April, and fire locations for the day before.Top-right: Statistics of **Significant Tornado Paramter (STP)** used in tornado forecasting (Thompson et al., 2003) from WRF-Chem simulations **with** fire emissions and data assimilation (blue) and **without** fire emissions (red). Statistics are computed for the mean near-storm environment for each tornado, with numbers on top of each panel representing the number of tornadoes that go into the statistics and "*" showing significant differences at the 5% p-value level. Bottom-right: Map of mean STP differences for the outbreak period between the two simulations.*

The Southeast Pacific
A Climate and Aerosol Modeling Challenge

The world's most widespread, persistent subtropical low cloud regime.



- WRF-Chem v3.3 CBMZ-MOSAIC/MYNN/Lin
- Fine vertical resolution: 75 levels, ~60m Δz < 3km
- Long spin-up: ~3-4 days

Reference: *Wood et al.* (2011)

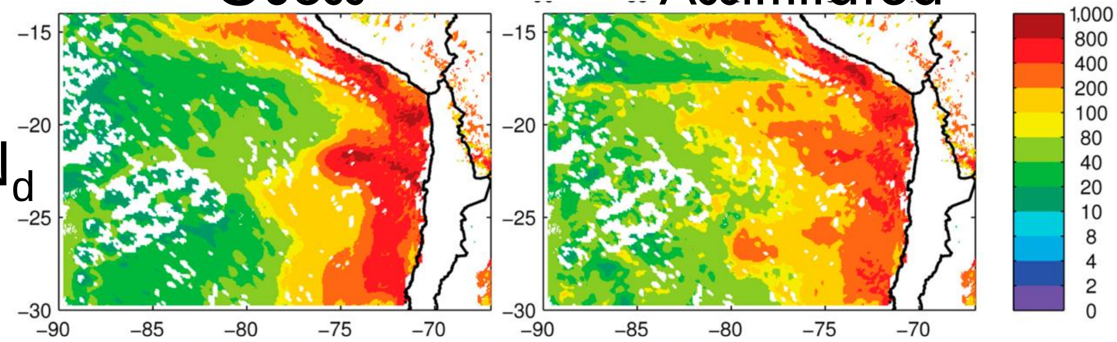
Assimilation results: + & - biases reduced

- Assimilate MODIS Terra N_d
- Aerosol mass and number are changed

WRF-Chem Guess

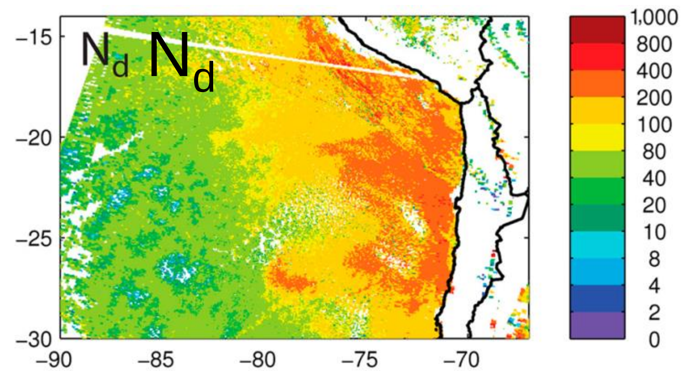
WRF-Chem Assimilated

N_d



MODIS Obs

N_d N_d

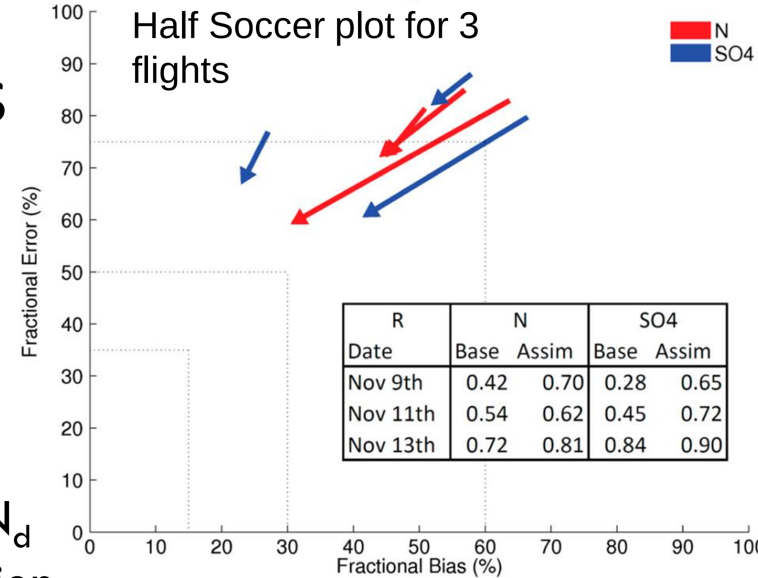


Ref: Saide et al., PNAS 2012

Daytime N_d after assimilation vs GOES and in-situ aerosol

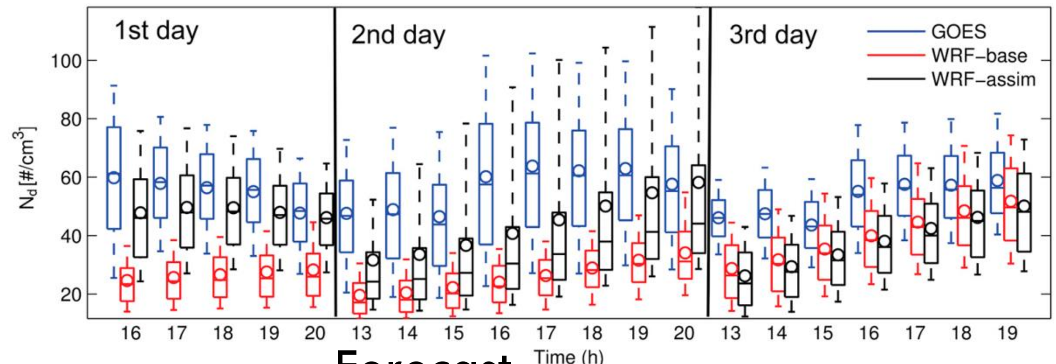
20

- Large improvements during the first 2 days for all domain
- GOES Assimilation improves agreement with VOCALS-REx C130 aerosol number and mass observations

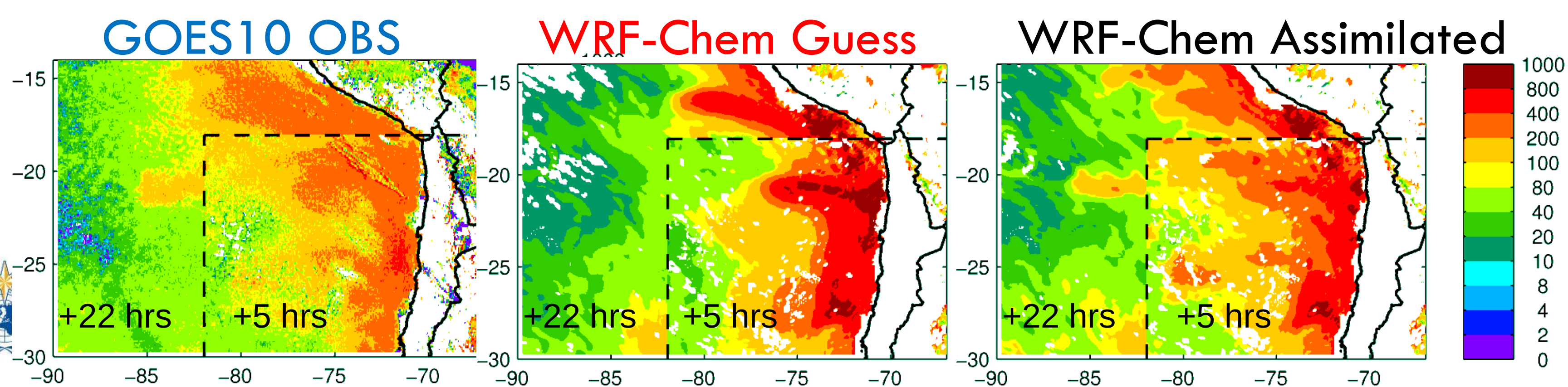


R	N		SO4	
Date	Base	Assim	Base	Assim
Nov 9th	0.42	0.70	0.28	0.65
Nov 11th	0.54	0.62	0.45	0.72
Nov 13th	0.72	0.81	0.84	0.90

A single MODIS N_d Assimilation



Forecast



Ref: Saide et al., PNAS 2012

Daytime N_d after assimilation vs GOES and in-situ aerosol

Saide et al., PNAS, 2013

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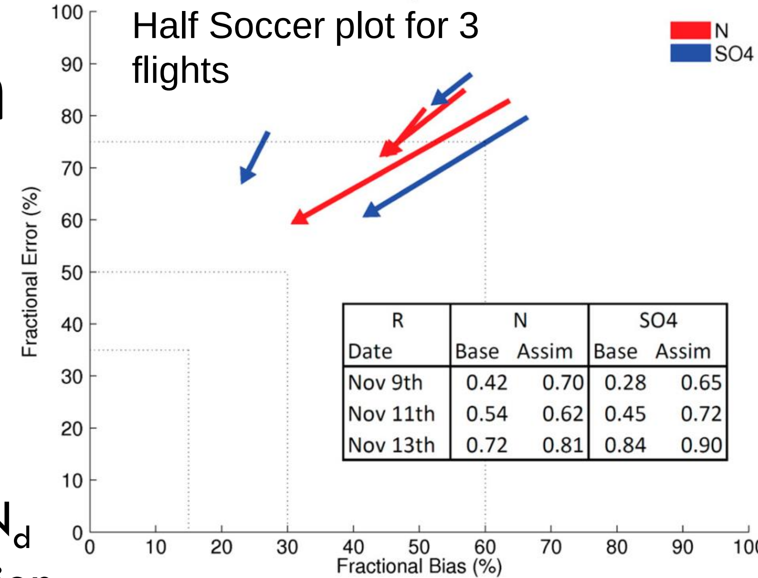

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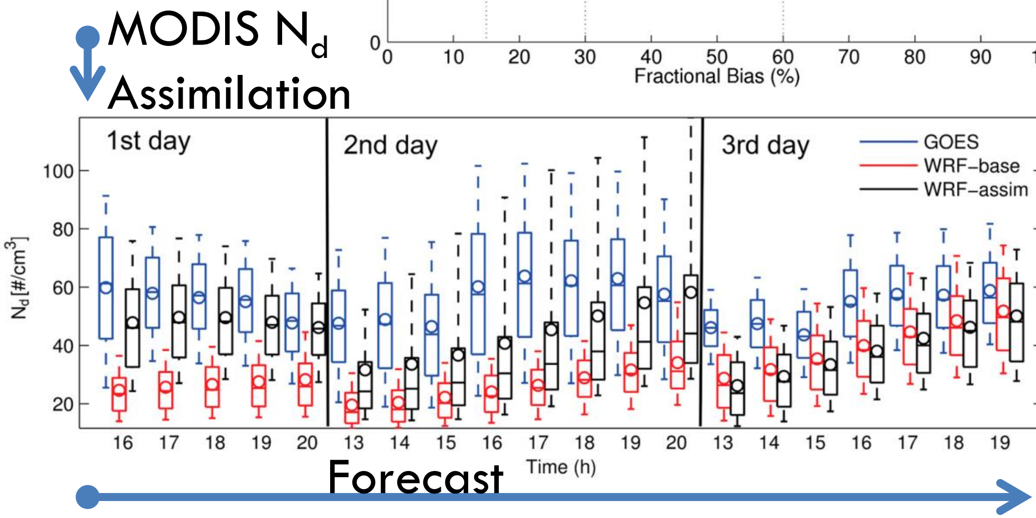
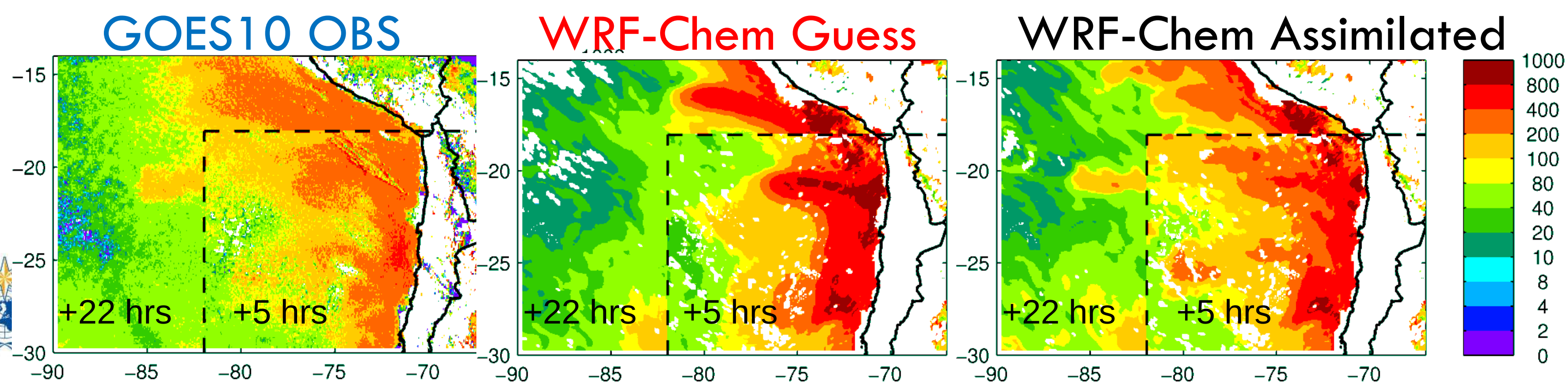
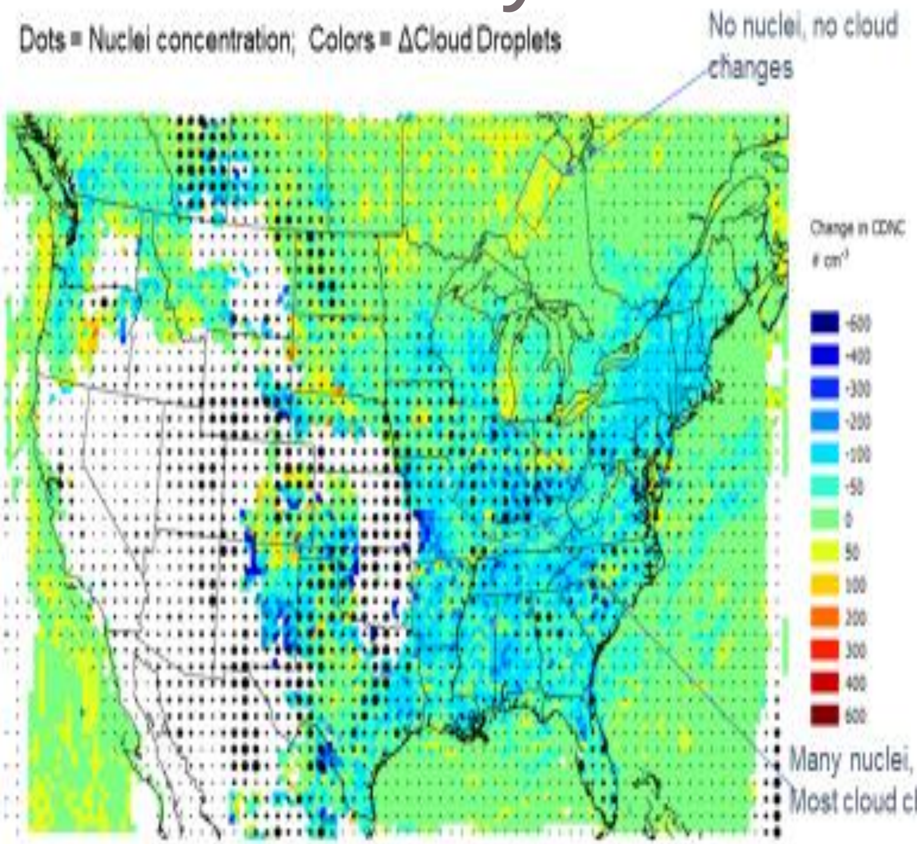


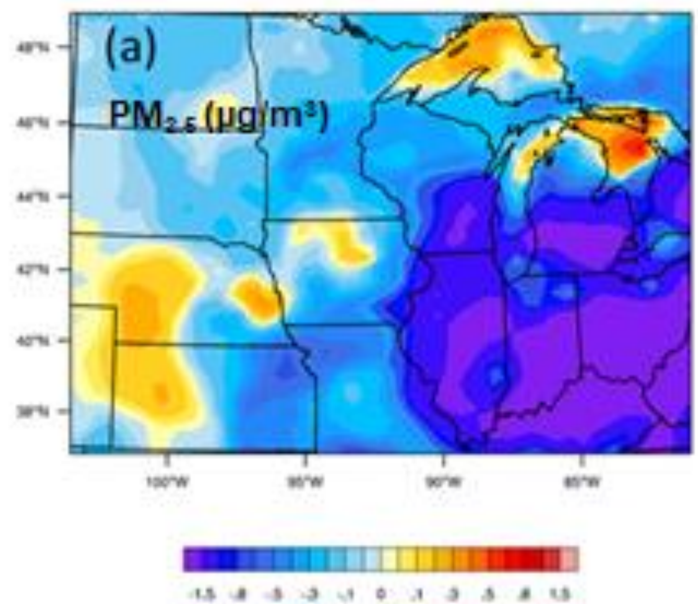


Coupled Size-Resolved Model Configuration to Study New Particle Formations



igure 2. Visualization of the result from D19 on aerosol-cloud interactions in the nucleation explicit variant of WRF-

8% Decrease in surface PM2.5 and 13% decrease in PM2.5 sulfate



Aerosol and Air Quality Research, 19: 204–220, 2019

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2018.05.0163

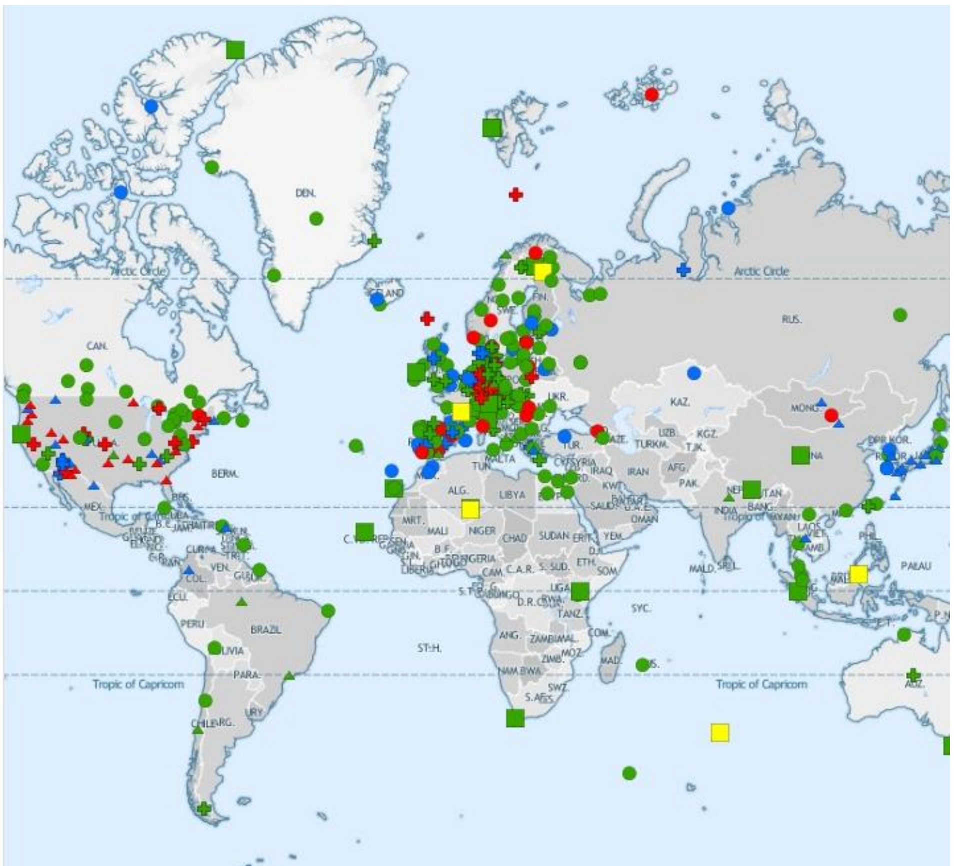
Impacts of New Particle Formation on Short-term Meteorology and Air Qual Determined by the NPF-explicit WRF-Chem in the Midwestern United State

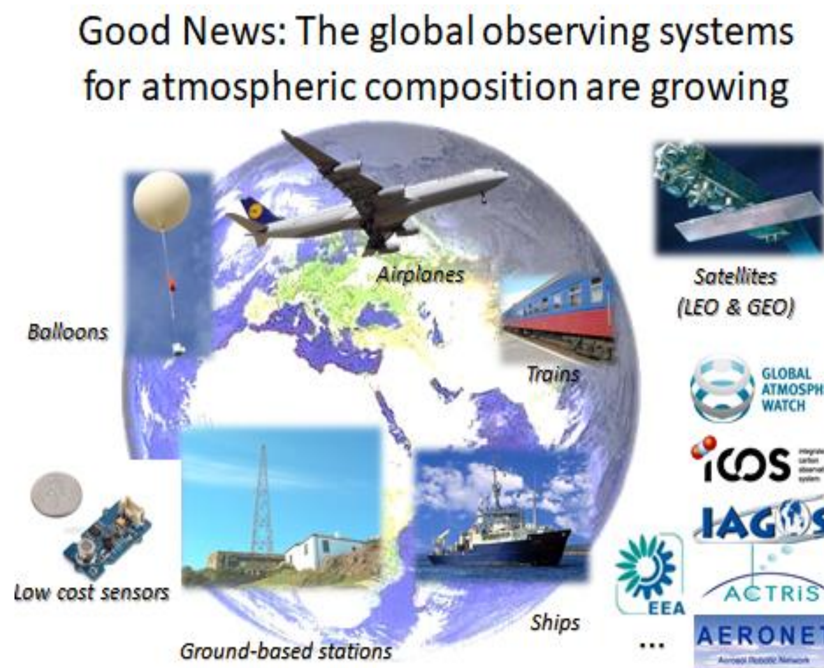
Can Dong[1], Hitoshi Matsui[2], Scott Spak[3], Alicia Kalafut-Pettibone[4], Charles Stanier[1*]

How observations are used for atmospheric composition applications?

Timeliness	Real-Time	Near-Real-Time	A posteriori	Final
	< 2-3 hours	< 2-3 days	< 1 month	1-2 year
QA/QC	Automated Filtering, flagging	Semi-automated	Manual, Expertise Semi-validated	Expertise+ Validated
Applications	Primary: • assimilation/ forecast • inverse modelling of emissions and fluxes Secondary: • Verification of products	Primary: • Verification of products Secondary: • assimilation • inverse modelling of surface emissions and fluxes (for Delayed-Mode applications)	• Validation of models and products • interim reanalyses • R&D	• reanalyses • Climate Data Records • Assessments • Validation of models and products • R&D

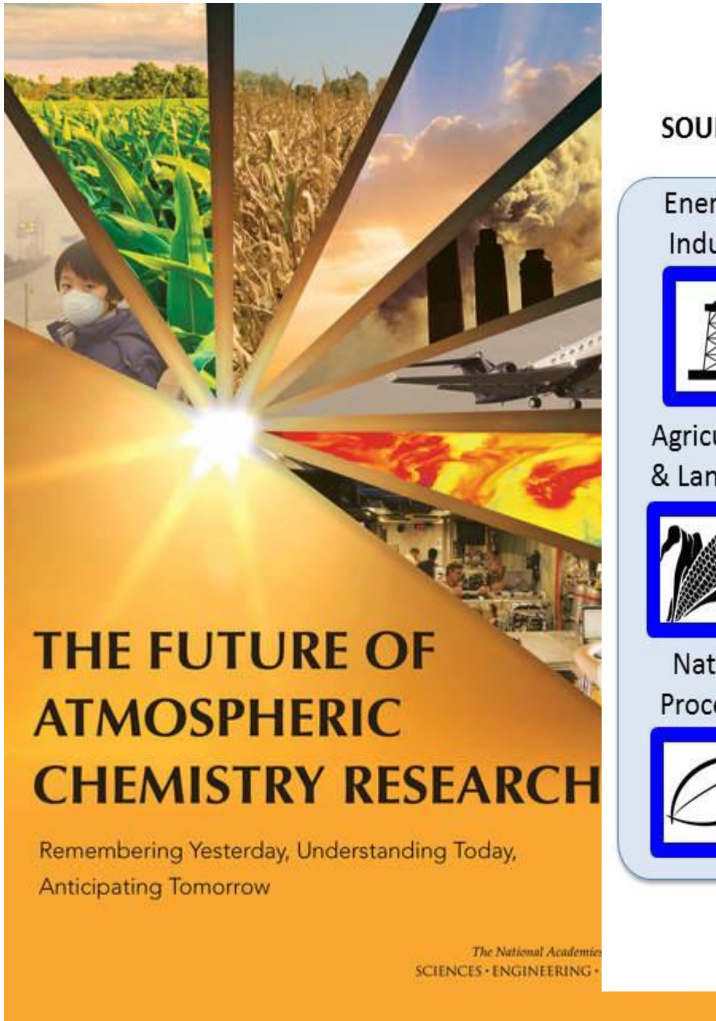
Scarcity of data --
common need to enhance observing system

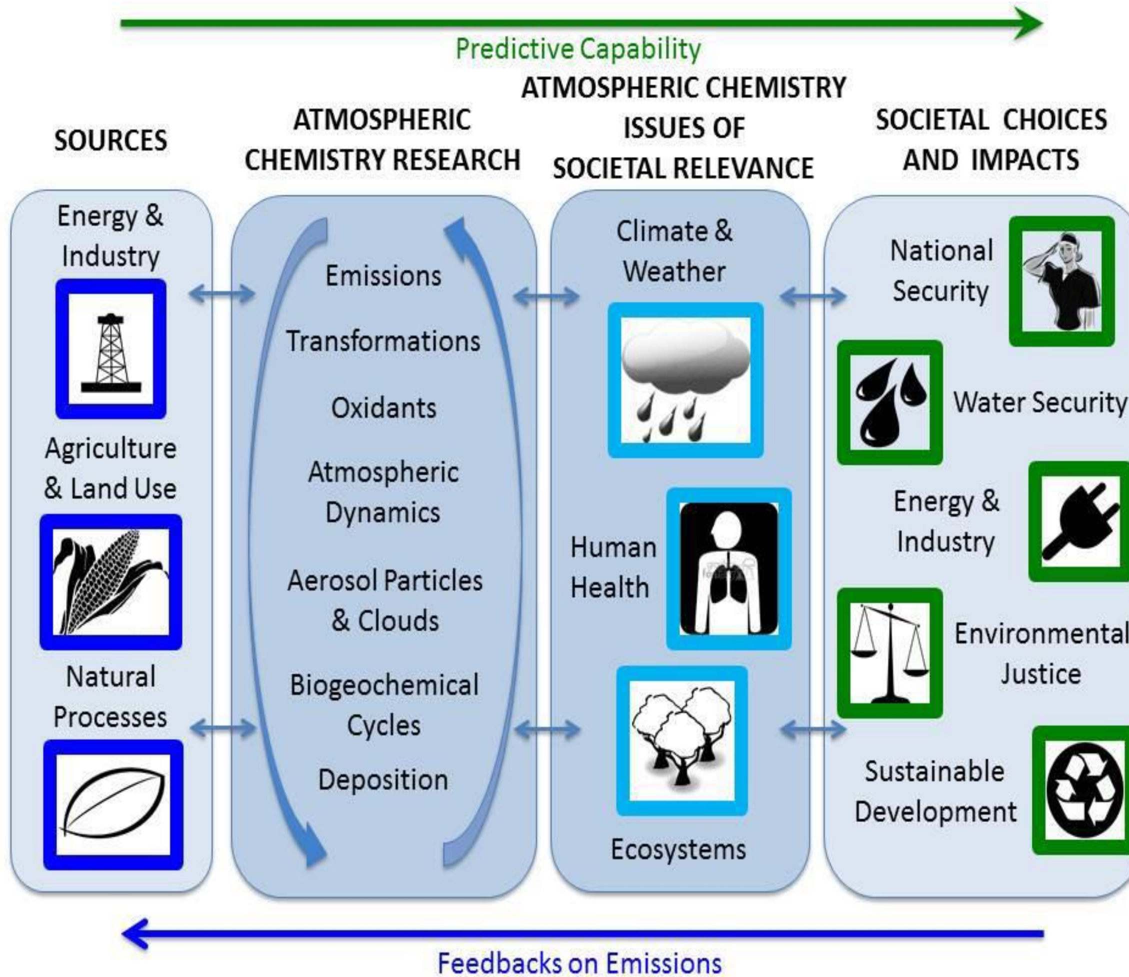




WMO OMM

An overarching goal of research is to enable ***Predictive Capability*** ***(S4S; R2O)***





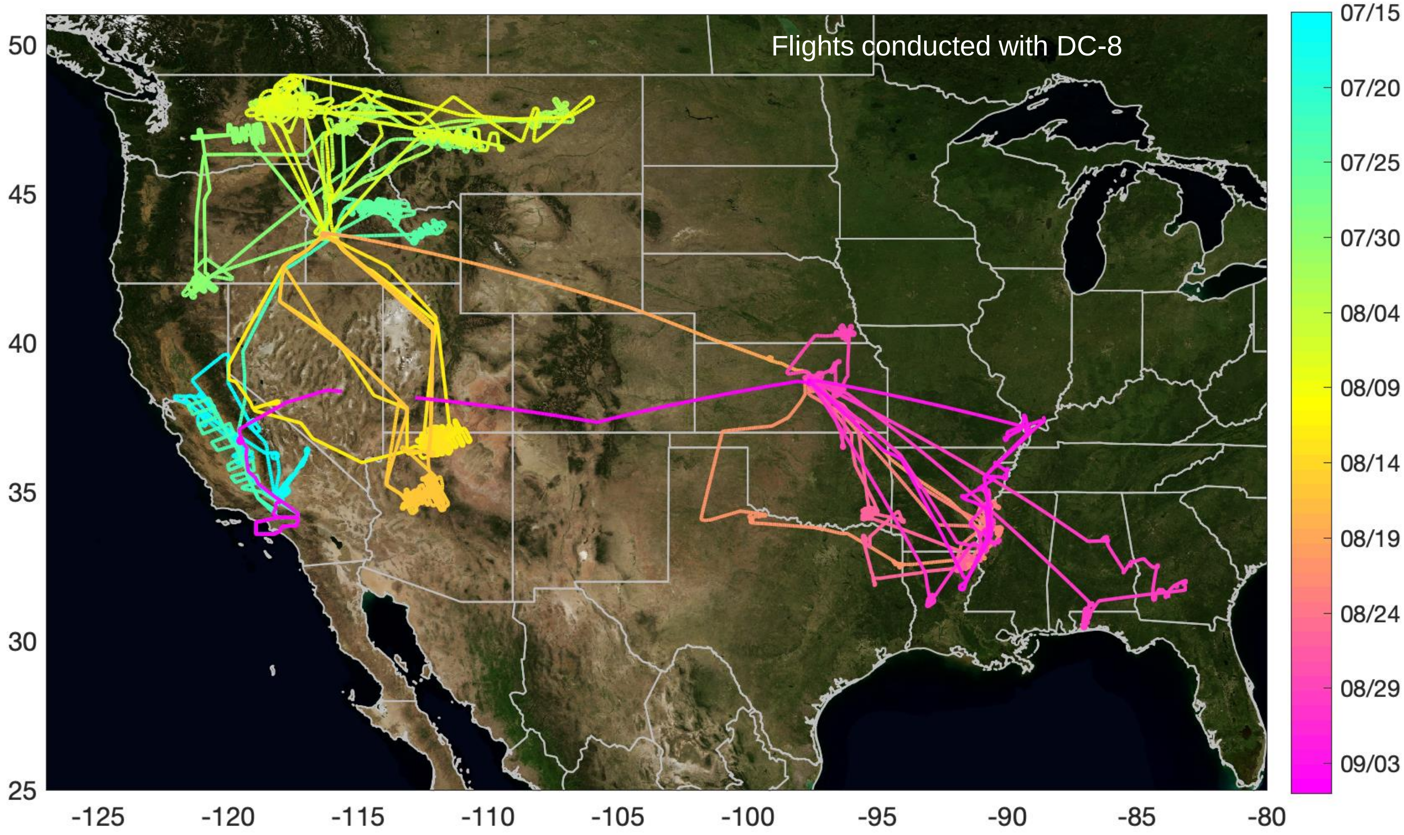
Vision for science

WMO OMM

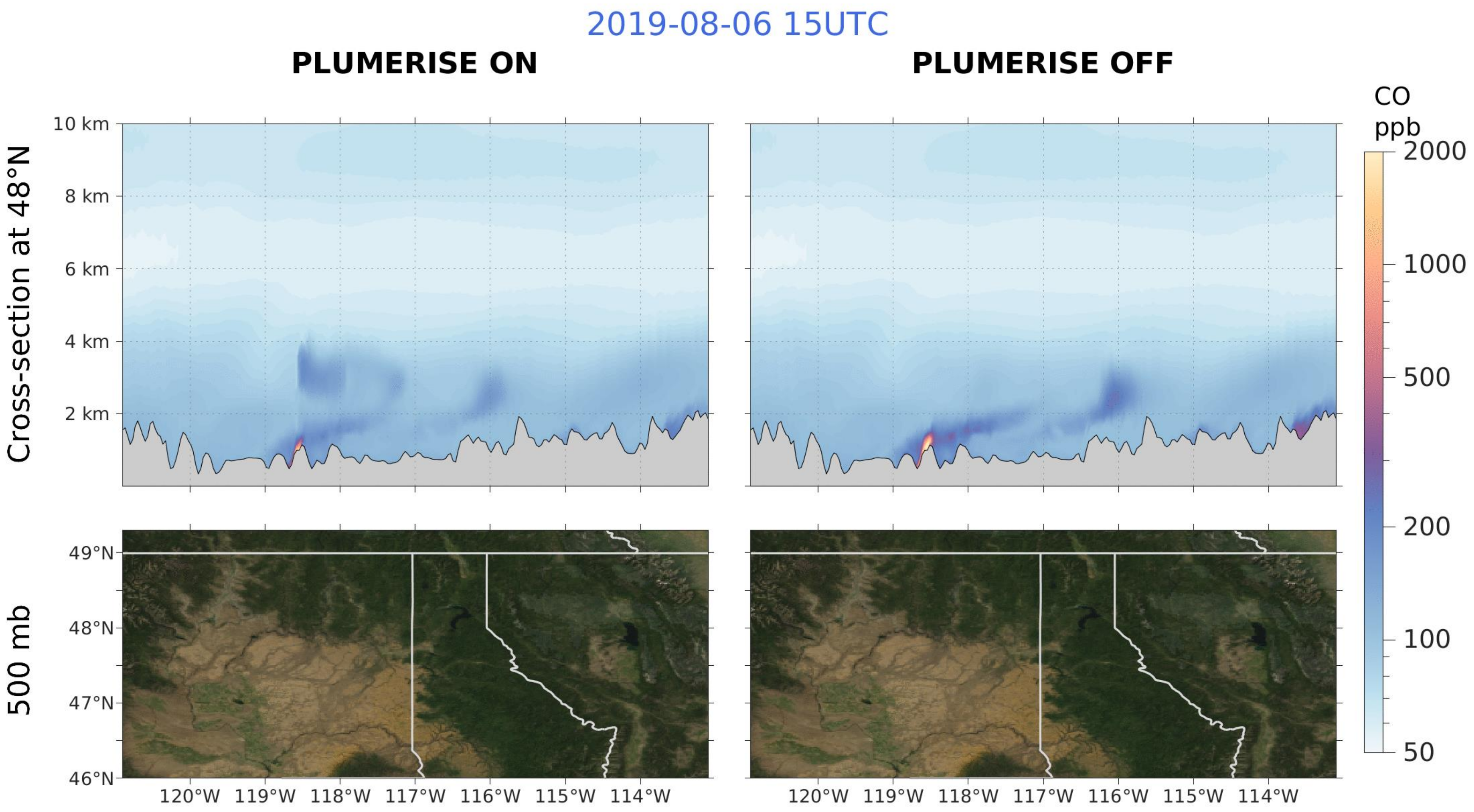
FIREX-AQ: Fire Influence on Regional to Global Environments Experiment - Air Quality

Objective:
Provide comprehensive observations to investigate the impact on air quality and climate from wildfires and agricultural fires across the continental United States.

More info:
https://esrl.noaa.gov/csd/projects/firex-aq/



Impacts of plume rise process



NASA - Aerosol, Clouds, Convection and Precipitation (A-CPP) Study